

Process Control



Notes

PROCESS CONTROL (IT62)
SEMESTER: VI
BRANCH: INSTRUMENTATION TECHNOLOGY

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Brief Syllabus:

- Chapter 1 : Controller Principles
- Chapter 2 : Analog Controllers
- Chapter 3 : Control Loop Characteristics
- Chapter 4 : Controllers, Transmitters, Converters and Relays
- Chapter 5 : P & ID Symbols and Diagrams.

Textbooks:

1. Process Control Instrumentation Technology (7th Edition) by Curtis D. Johnson, Pearson Education Publications (Low Price Edition), 2003.
[For Chapter 1, 2 and 3]
2. Instrument Engineers Handbook: Volume 1-Process Measurement, Volume 2-Process Control, by Bela J. Liptak, Chilton Book Company.
[For Chapter 4 & 5]

PROCESS CONTROL

Course Overview:

The course offers a detailed study of process control with emphasis on different types of controllers and their principles, characteristics, implementation, quality, stability and tuning, which is quite essential for an instrumentation engineer to work in any process industries. The course provides a fundamental knowledge to instrumentation engineer regarding the implementation of controller techniques in the process industries. The course also provides a basic knowledge about process & instrumentation drawing symbols and diagrams.

Course Objective:

At the end of this course an instrumentation technology student will become familiar with process control tools and he/she will be in a position to measure, acquire and control the process parameters in process industries.

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Chapter 1

CONTROLLER PRINCIPLES

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PROCESS CONTROL (IT62)

Chapter 1 : Controller Principles

1.1 Introduction

In this chapter, we study the nature of controller action for systems with operations and variables that range over continuous values. The controller inputs the results of measurements of the controller variable and determines an appropriate output to the final control element. Essentially, the controller is some form of computer – either analog or digital, pneumatic or electronic. Using measurements, the controllers solve the certain equations to calculate the proper output. The equations necessary to obtain the control are independent of both process and controller function (i.e. analog or digital). The equations describe the modes or action of controller operation. The nature of process and controlled variable determine which mode of control to be used and the certain constants in the mode equation.

1.2 Objectives

At the end of this chapter you will be able to:

- Define & understand the process characteristics
- Define & understand the process system parameters
- Describe the discontinuous and continuous controller modes
- Compare and differentiate discontinuous and continuous controller modes
- List the advantages and disadvantages of discontinuous and continuous controller modes
- Describe the composite controller modes
- Advantages and disadvantages of composite controller modes

1.3 Process Characteristics

The selection of what controller modes to use in a process is a function of the characteristics of the process. The following prominent characteristics of process are helpful in understanding the controller modes and also in selection of appropriate controller mode for implementation. To define and understand the various process characteristics we will take an example of a process control loop as shown in Fig 1.1.

1.3.1 Process Equation

A process control loop regulates some dynamic variable in a process. This controlled variable, a process parameter, may depend on many other parameters in the process and thus suffer changes from many different sources. If the measurement of controlled variable deviates from the setpoint, then the controlling parameter will change, this in turn changes the controlled variable.

The *process equation* is a function which describes the process and provides the information about other process parameters which influence the controlled variable. In

the process equation it is not necessary to know the exact functional relationship of process parameters and nor it requires the linearity of the function.

Consider the control of liquid temperature in a tank as shown in Fig 1.1, the *controlled variable* is the liquid temperature T_L . The liquid temperature is depends on the many other parameters such as, input flow rate via pipe A (Q_A), output flow rate via pipe B (Q_B), ambient temperature (T_A), steam temperature (T_S), inlet temperature of the liquid (T_O) and the steam flow rate (Q_S). In this example Q_S is the *controlling parameters* because this can be varied through controller to provide the control over controlled variable (T_L) to achieve the setpoint.

The above process can be described by a simple process equation for liquid temperature T_L as follows:

$$T_L = f(Q_A, Q_B, Q_S, T_A, T_S, T_O) \quad (1.1)$$

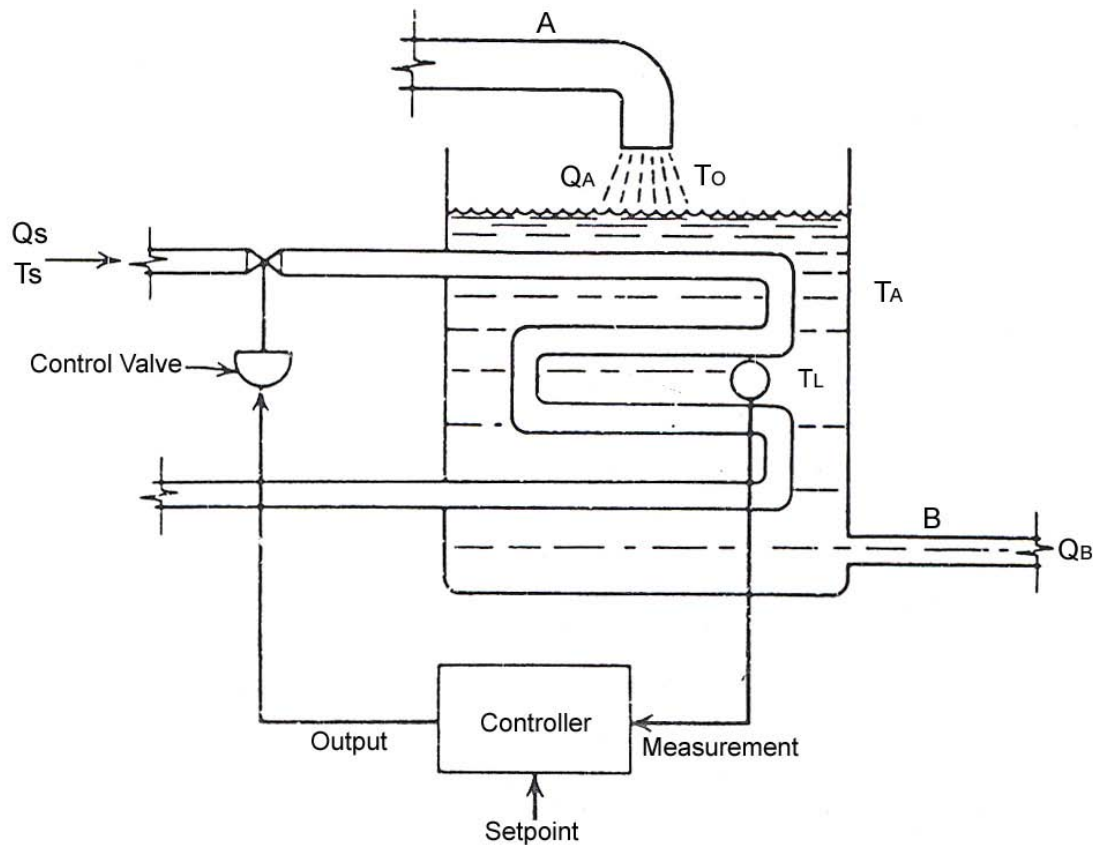


Fig. 1.1 Control of liquid temperature in a tank by process control

1.3.2 Process Load

The process equation provides the set of values of process parameters which results in the controlled variable to reach setpoint. The *process load* refers to set of all process parameters excluding the controlled variable and set of parameters is called *nominal set*. When all the process parameters have their nominal value then the load on the system is called *nominal load*. The required controlling variable value under nominal load is called

nominal value of that parameter. If one of the parameter changes which in turn changes the controlled variable to deviate from setpoint, than it is called a *process load change* has occurred.

If one of the parameter changes temporarily and returns to nominal value then it is called a *transient* has occurred.

In the example of Fig 1.1, a process load change can be caused by a change in any of the five parameters affecting the liquid temperature.

1.3.3 Process Lag

Whenever a process load change or transient occurs, it causes a change in the controlled variable. The process control loop responds to this change to ensure that, after some finite time the controlled variable reaches the setpoint. The part of this time consumed by process itself is called *process lag*.

In the example of Fig 1.1, if process load change occurs, then it will affect the controlled variable (T_L). The control loop responds immediately by adjusting the steam flow rate. But there will be some time delay in opening the control valve and heating process which contribute to the process lag. In most of the process control systems the loop reacts faster than the process, and there is no advantage in designing control systems many times faster than the process lag.

1.3.4 Self-Regulation

A significant characteristic of some processes to adopt a specific value or stable value of controlled variable under nominal load without regulation via process control loop is called self-regulation. The control operations are significantly affected by the self-regulation.

1.4 Control System Parameters

1.4.1 Error

The deviation of controlled variable from the setpoint is called error. The error is given by the following equation:

$$e = r - b \quad (1.2)$$

where, e = error

b = measured value of variable

r = setpoint of variable (desired or reference)

Example: If the setpoint in a 4-20 mA range corresponds to 7.5 mA and the measured value is 10.0 mA, then the error is -2.5 mA. This current error has little direct meaning unless it is related the controlled variable. It is necessary to work back and prove that this error corresponds to some flow rate of 1.5 Lit/min, or a pressure of 2.5 kPa etc.

To describe controller operation in a general way, it is better to express the error as percent of the measured variable range (i.e., the span). To express error as percent span, it

is necessary only to write both the setpoint and measurement in terms of percent span and take the difference according to equation (1.2).

$$e_p = \frac{r - b}{b_{\max} - b_{\min}} \times 100 \quad (1.3)$$

where, e_p = error as percent span
 b_{\max} = maximum value of measured variable
 b_{\min} = minimum value of measured variable

Example: If the setpoint in a 4-20 mA range corresponds to 7.5 mA and the measured value is 10.0 mA, then the error in % is -15.625.

The positive error indicates the measurement below the setpoint and negative error indicates the measurement above the setpoint.

1.4.2 Variable Range

The variable range can be expressed as the minimum and maximum value of the variable or the nominal value plus the deviation spread about the nominal value. If a standard 4-20 mA signal transmission is employed, the 4 mA represents the minimum value of the variable and 20 mA the maximum. If the deviation for variable is mentioned as ± 0.1 mA, then the variable range will be from 3.9 mA to 20.1 mA. In computer based control systems all 0's are minimum value of the variable and all 1's are the maximum value.

1.4.3 Control Parameter Range

Control parameter range is the range associated with the controller output. The final control element has some minimum and maximum effect on the process. The controller output range is the translation of output to the range of possible values of the final control element.

The control parameter range can also be expressed as 4-20 mA standard signal, with minimum and maximum effects will be in terms of minimum and maximum current. The controller output will be expressed as percentage where 0% is minimum and 100% is maximum.

The controller output as a percent of full scale when the output varies between specified limits is given by the following equation:

$$p = \frac{u - u_{\min}}{u_{\max} - u_{\min}} \times 100 \quad (1.4)$$

where, p = controller output as percent of full scale
 u = value of the output
 u_{\max} = maximum value of controlling variable
 u_{\min} = minimum value of controlling variable

1.4.4 Control Lag

The control system also has a lag associated with its operation that must be compared with process lag for appropriate control action. When controlled variable experiences

sudden change, the process control loop reacts by giving command to final control element to adopt a new value to compensate for the detected change with respect the setpoint and this event takes some time.

Control lag refers to the time for the process control loop to make necessary adjustments to the final control element.

1.4.5 Dead Time

Dead time is the elapsed time between the instant a deviation (error) occurs and when the corrective action first occurs. This time is a function of both process and process control system.

An example for dead time is the control of chemical reaction by varying reactant flow through a long pipe.

1.4.6 Cycling

Cycling is defined as the oscillations of the error about zero value or nominal value. This means that the variable will be cycling above and below the setpoint value.

Steady-state cycling is one in which oscillations will continue indefinitely. In such conditions peak amplitude of error and period of oscillations are important in understanding the nature of process variable. Transient cycling is one in which oscillations will decay to zero after some time. In such conditions initial error and period of cyclic oscillations are important in understanding the nature of process variable.

Problem 1

A velocity control system has a range of 220 to 460 mm/s. If the setpoint is 327 mm/s and the measured value is 294 mm/s, calculate the error as % of span.

Solution

Given data: Range of velocity = 220 to 460 mm/s,
 $b_{\max} = 460$ mm/s $b_{\min} = 220$ mm/s
 Setpoint (r) = 327 mm/s
 Measured value = 294 mm/s
 $e_p = ?$

$$e_p = \frac{r - b}{b_{\max} - b_{\min}} \times 100$$

$$e_p = [(327 - 294) / (460 - 220)] \times 100$$

$$e_p = 13.75\%$$

Problem 2

A controlling variable is a motor speed that varies from 800 to 1750 rpm. If the speed is controlled by a 25 to 50 v dc signal, calculate (a) the speed produced by an input of 38 v, and (b) the speed calculated as a percent of span.

Solution

Given data: Range of motor speed = 800 to 1750 rpm
 Control signal voltage range = 25 to 50 v
 (a) Speed (S) = ? when input voltage (V_{in}) = 38 v
 (b) Speed as percent span (p) = ?

The linear relationship between speed and voltage is given by the basic equation:

$$S = mV_{in} + c$$

The simultaneous equations for the above range are:

For low range signal $800 = 25m + c$

For higher range signal $1750 = 50m + c$

Solving the above simultaneous equations we get:

$$m = 38 \text{ \& } c = -150$$

The equation for the speed can be given by

$$S = 38V_{in} - 150$$

(a) When $V_{in} = 38$ v, $S = 38 \times 38 - 150 = 1294$ rpm

(b) Speed calculated as % of span (i.e, controller output)

$$P = [(S_p - S_{\min}) / (S_{\max} - S_{\min})] \times 100$$

$$P = [(1294 - 800) / (1750 - 800)] \times 100$$

$$P = 52\%$$

1.4.7 Controller Modes

Controller modes refer to the methods to generate different types of control signals to final control element to control the process variable.

Broad classifications of different controller modes used in process control are as follows:

- (1) Discontinuous Controller Modes
 - (a) Two-position (ON/OFF) Mode
 - (b) Multiposition Mode
 - (c) Floating Control Mode: Single Speed and Multiple Speed
- (2) Continuous Controller Modes
 - (a) Proportional Control Mode
 - (b) Integral Control Mode
 - (c) Derivative Control Mode
- (3) Composite Controller Modes
 - (a) Proportional-Integral Control (PI Mode)
 - (b) Proportional-Derivative Control (PD Mode)
 - (c) Proportional-Integral-Derivative Control (PID or Three Mode Control)

Based on the controller action on the control element, there are two modes:

- (1) *Direct Action*: If the controller output increases with increase in controlled variable then it is called direct action.
- (2) *Reverse Action*: If the controller output decreases with increase in controlled variable then it is called reverse action

The choice operating mode for any given process control system is complicated decision. It involves not only process characteristics but cost analysis, product rate, and other industrial factors. The process control technologist should have good understanding of the operational mechanism of each mode and its advantages and disadvantages.

In general, the controller operation for the error e_p is expressed as a relation:

$$p = F(e_p) \quad (1.4)$$

where $F(e_p)$ represents the relation by which the appropriate controller output is determined.

1.5 Discontinuous Controller Modes

In these controller modes the controller output will be discontinuous with respect to controlled variable error.

1.5.1 Two-Position (ON/OFF) Mode

The most elementary controller mode is the two-position or ON/OFF controller mode. It is the simplest, cheapest, and suffices when its disadvantages are tolerable. The most general form can be given by:

$$P = \begin{cases} 0 \% & e_p < 0 \\ 100 \% & e_p > 0 \end{cases} \quad (1.5)$$

The relation shows that when the measured value is less than the setpoint (i.e. $e_p > 0$), the controller output will be full (i.e. 100%), and when the measured value is more than the setpoint (i.e. $e_p < 0$), the controller output will be zero (i.e. 0%).

Neutral Zone: In practical implementation of the two-position controller, there is an overlap as e_p increases through zero or decreases through zero. In this span, no change in the controller output occurs which is illustrated in Fig. 1.2.

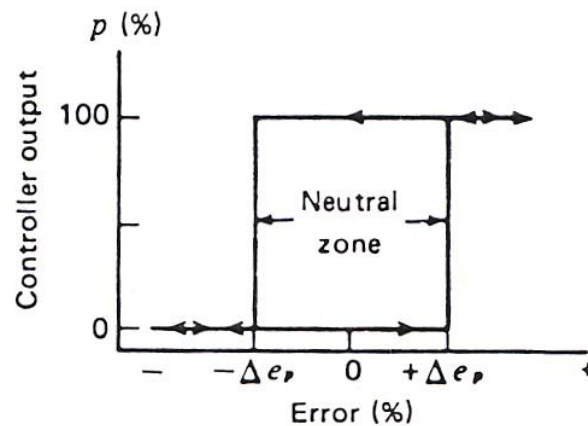


Fig. 1.2 Two-position controller action with neutral zone.

It can be observed that, until an increasing error changes by Δe_p above zero, the controller output will not change state. In decreasing, it must fall Δe_p below zero before the controller changes to 0%. The range $2\Delta e_p$ is referred to as *neutral zone* or *differential gap*. Two-position controllers are purposely designed with neutral zone to prevent excessive cycling. The existence of such a neutral zone is an example of desirable hysteresis in a system.

Applications: Generally the two-position control mode is best adapted to:

- Large-scale systems with relatively slow process rates
Example: Room heating systems, air-conditioning systems.
- Systems in which large-scale changes are not common
Examples: Liquid bath temperature control, level control in large-volume tanks.

Problem 3

A liquid-level control system linearly converts a displacement of 2 to 3 m into a 4 to 20 mA control signal. A relay serves as the two-position controller to open and close the inlet valve. The relay closes at 12 mA and opens at 10 mA. Find (a) the relation between displacement level and current, and (b) the neutral zone or displacement gap in meters.

Solution

- Given data: Liquid-level range = 2 to 3 m i.e. $H_{\min} = 2\text{m}$ & $H_{\max} = 3\text{m}$
 Control signal range = 4 to 20 mA i.e. $I_{\min} = 4\text{mA}$ & $I_{\max} = 20\text{mA}$
- (a) Relation between displacement level (H) and current (I)
 (b) Neutral zone (NZ) in meters.

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